financed. Improved roadside appearances are actually a measure of a well-maintained roadway and represent the department's concern for the environment through which the roadway passes.

REFERENCE

1. AASHTO Maintenance Manual. American Association of State Highway and Transportation Officials, Washington, DC, 1976.

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Abridgment

Minimizing Roadway Salt Problems in Maine

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In an effort to reduce the salt problems in Maine that have resulted from winter maintenance operations, a three-phase program was implemented: (a) early detection of salt toxicity to vegetation, (b) reduction in the amount of salt used, and (c) dispersal of sodium ions in the soil. Aerial-photograph interpretation by using color infrared photography was developed for early detection of vegetation damage. Reduction in the amount of salt used was achieved through calibration of salt-spreading equipment and through intensive yearly instructional meetings to inform the operators of the importance of reducing salt use. These two methods allowed the Maine Department of Transportation to reduce the use of salt from 99 000 t (110 000 tons) in the winter of 1967-1968 to 57 600 t (64 000 tons) in the winter of 1978-1979. Sodium-induced stresses on vegetation were further reduced by dispersing sodium ions in the soil through the application of gypsum.

To minimize the effects of salt (NaCl) on the environment and reduce costs, the Maine Department of Transportation (MDOT) developed a method of detecting early damage to vegetation by using color infrared photographs, a program to control the amount of salt applied, and a method for alleviating the sodium toxicity of soil.

Through the use of aerial-photograph interpretations of color infrared photography, it was possible to obtain information on damage that possibly resulted from saline runoff. This method made it possible to determine whether any vegetation damage was visible for the areas adjacent to the roadway and/or salt-storage areas.

Once sodium toxicity to vegetation became evident, it was difficult to correct. However, for some situations it was found desirable to lower sodium levels of the soil in order to reduce the toxicity to vegetation. Thus, research was undertaken to determine whether some means of alleviating this problem was possible. Through this effort, gypsum ($CaSO_4$) was found beneficial in lowering sodium levels in soil.

METHODOLOGY

The first phase was to determine whether vegetation damage existed and whether the damage resulted from saline runoff. This was accomplished by the use of color infrared photography. The second phase, on which the main emphasis was placed, was to reduce the amount of salt used, thus preventing as many salt-related problems as possible. The third phase was the use of gypsum to disperse the sodium ions in the soil.

Detecting Vegetation Damage

It was determined to be feasible to use aerial-photograph interpretation techniques in order to detect possible early vegetation damage that might be salt related. The objectives were to locate and map damaged areas, analyze possible causes, and recommend corrective action.

Color and color infrared 35-mm photographs were used for the study areas; the photographs were taken at various stages of foliage development, from the budding through the coloration period. The aerial photographs were taken from oblique through near vertical angles by means of a hand-held 35-mm camera. It was possible by use of color infrared photography to distinguish healthy vegetation from the damaged vegetation within an area, especially if the area contained the same tree species. Color infrared photography provided the highest image contrast between the healthy and damaged species late in the growing season.

There are other causes for stress, such as blight, insects, plant diseases, herbicides, winter kill, and modification of groundwater level by cuts, embankments, and culverts. However, salt in combination with poor drainage conditions does cause considerable damage. Assistance from forestry personnel may be required to determine the cause of early stress.

Reducing the Salt Application

Various procedures were instituted to keep the use of salt to an absolute minimum and still maintain the desired results. The equipment was calibrated and personnel were trained so that only the desired amount of salt was used. MDOT generally tried to use 113 kg per two-lane kilometer (400 lb per two-lane mile) per application. Although a reapplication was sometimes needed, which required additional work and truck hours, there was still an overall dollar saving.

MDOT reduced the use of salt by attacking the problem in three ways:

1. Old equipment was modified so that it could be calibrated; newer equipment was purchased with calibration in mind.
2. Yearly instructional meetings were held with the operators of all equipment to reinforce MDOT's position on the importance of reducing salt use. These meetings were followed by shorter meetings at the division office level.
3. Supervisors inventoried the salt used in each of the divisions. This information was provided to the division engineers so that they could take corrective action if it appeared that salt use was

Figure 1. Chemical reaction.

$$\frac{\text{Soil}}{\text{Particle}} \begin{matrix} Na^{+} \\ Na^{+} \end{matrix} + CaSO_4 \longrightarrow \frac{\text{Soil}}{\text{Particle}}\ Ca^{++} + \underset{\text{(soluble)}}{Na_2SO_4}$$

excessive in any area through errors of either practice or judgment.

In addition to actual control of the amount of salt used, other procedures were implemented as part of a total salt-reduction program. First, plowing operations commenced as soon as snow had accumulated to any appreciable extent. During a winter storm watch, MDOT begins to plow when the snow accumulation reaches 1.27 cm (0.5 in) and it is still snowing. In addition, where positive down pressure could be applied, underbody plows were used. This method partly replaced chemical action with mechanical force, thus requiring less salt. A third method was to use tungsten carbide plow blades without plow shoes. This type of blade rode on the surface and cleaned nearly all the snow from the roadway surface.

Salt Restrictor

One of the more successful pieces of equipment used by MDOT was a restrictor. The restrictor is a simple device employed only on hydraulic tailgate sanders. The tailgate sanders were equipped with an auger shaft that ran the width of the body into a 25-cm (10-in) opening on the left side of the tailgate.

The restrictor, which was adjustable on the shaft, limited free flow and allowed the flow of salt to be regulated. A 1.27-cm (0.5-in) gap between the restrictor and auger opening released the desired application rate at normal speeds. Hard-weld beads on the inside of the restrictor plates aid in grinding the cakes of salt.

Because the auger speed varied between trucks, a chart was developed that related the speed of the auger to the flow of salt for the 1.27-cm gap. A table was developed to convert the flow in pounds per minute to pounds per mile per hour.

Hopper Sander Calibration

Every hopper sander was calibrated at nine individual settings. The discharge gate was set at 2.54-, 5.08-, and 7.62-cm (1-, 2-, and 3-in) openings, and the hydraulic control that regulated the speed of the feed belt was set at three separate settings with each gate change. Calibration took an average of approximately 35 min to complete.

The operator was instructed to race the engine to a working engine speed (1100-1500 RPM for diesel-powered equipment and 2000-2500 RPM for gasoline-powered equipment), put the hopper belt in gear, and discharge salt for 60 s. The weight of the salt discharge was recorded. This process was repeated for each individual setting. For convenience and ease of handling, a 0.03-m^3 (1 ft^3) box was used for weighing. This box was weighed and the net weight recorded. Usually, a setting would contain two to five full boxes plus a partial box that also would be weighed. The calibrations ranged from 23 to 227 kg (50-500 lb) of salt/min. The calibration results were returned to the office and transferred to a calibration chart that was then returned to the operator of the equipment. It was found that no two pieces of equipment calibrated the same, which made it necessary to calibrate all of the hoppers.

Alleviating Sodium Toxicity

A study completed by F.E. Hutchinson in 1965 and 1966 (1) indicated the sodium and chloride levels were a function of the length of time and the amount of salt applied to the highway. He also found that the higher sodium and chloride levels in the soil were near the edge of the highway, within 15 m (50 ft). Soil samples obtained at 0, 9, and 18 m (0, 30, and 60 ft) indicated minimum sodium and chloride levels beyond the longitudinal roadway ditches.

In 1969 Hutchinson initiated a study to determine whether any means was available to remedy the problem of high sodium levels in soils adjacent to highways (2). Later MDOT made a follow-up study (3). Both of these studies focused on dispersal of sodium ions through surface applications of gypsum. These applications were made by using the gypsum both in the dry form and mixed with water to form a slurry. When a slurry was used, three methods of treatment were tried; surface treatment, surface treatment with aeration, and subsurface treatment. When gypsum is applied to a soil that has high sodium levels, the reaction is as shown in Figure 1.

Thus, when the sodium is replaced by calcium in the presence of sulfate ions (SO_4^{--}), a very soluble sodium sulfate is formed and leaches downward through the soil whenever water is available. It should be noted that as the $NaSO_4$ leaches downward it may enter into the groundwater supply and thus raise the sodium levels of the groundwater.

Field Methods of Application

A slurry mixture of 0.5 kg of gypsum per 1 L of water (4 lb/gal) applied with a hydroseeder unit was found to be the most satisfactory method of application; this method of application produced the largest percentage reduction in sodium levels for a one-year period--55 percent for the 0- to 15-cm (0- to 6-in) depth. Use of the hydroseeder eliminated the dust problem, and it was possible to obtain the desired application rate.

RESULTS

Aerial-photograph interpretation, reduction of the salt application, and alleviation of sodium toxicity provided results that minimize roadway salt problems.

Aerial-Photograph Interpretation

Aerial-photograph interpretation techniques provided the means for locating damaged vegetation that was, in some instances, more extensive than first believed. For example, there were cases in which it had been believed that only a few trees had been damaged but, after the photographs had been analyzed, it was found that many thousands of trees showed the early effects of salt toxicity. This finding was verified by field inspections and proved especially true when there had been saline runoff into a bog area. For streams and rivers, sodium and chloride levels were not a problem (4).

The decision to enclose salt-storage areas was based on information obtained from this type of findings, plus other factors such as keeping the salt dry, which allowed better control in application.

Reduction of Salt Application

Early in the program of salt reduction, when the application of salt on the highways was being investigated, it was ascertained that some operators had applied approximately 225-280 kg/km (800-1000 lb/mile) where 85-110 kg/km (300-400 lb/mile) would have been sufficient. At that time the only control over the amount of salt applied to the road was by adjusting the speed of the truck. During 1967-1968, 17.8 t/km (31.5 ton/mile) were applied each year. With only 25 percent of the trucks equipped with restrictors in the winter of 1968-1969, 15.8 t/km (28.0 ton/mile) were applied. In the winter of 1969-1970, after nearly 100 percent of the trucks had been equipped with restrictors, the application was 11.3 t/km (20.0 ton/mile).

During the winter of 1967-1968, MDOT had used more than 99 000 t (110 000 ton) of salt. However, following the policy of keeping salt used to an absolute minimum while maintaining desired results, it was possible to reduce the amount of salt to approximately 57 600 t (64 000 ton) per year in the winter of 1978-1979. The amount of salt used was reduced from 8.53 to 4.61 t/lane-km (15.14 to 8.18 tons/lane mile) although the length of state highways had increased from 11 761 to 12 614 lane-km (7308 to 7838 lane miles).

Alleviation of Sodium Toxicity

Where gypsum was applied, it appeared that the optimum rate of application was 24-34 t/hm^2 (10-15 tons/acre). This rate was based on replications of 0, 22, 34, and 45 t/hm^2 (0, 10, 15, and 20 tons/acre). These applications on a marine clay silt soil resulted in a 55 percent reduction of sodium ions at a depth of 0 and 15 cm (0 and 6 in), 30 percent at 15 and 30 cm (6 and 12 in), and 45 percent at 30 and 46 cm (12 and 18 in). This reduction was obtained over an 11-month period in an area that receives approximately 104 cm (41 in) of rainfall annually. In contrast, sodium levels increased in the control plots.

The application of gypsum is probably limited to urban and/or suburban areas where there is a serious problem of sodium toxicity to vegetation, because gypsum application is a relatively expensive procedure.

CONCLUSIONS

The effort to reduce salt problems that have resulted from highway maintenance operations produced the following results:

1. Aerial-photograph interpretations by using color infrared photography aided in the early detection of salt toxicity to vegetation.
2. Calibration of equipment, keeping the salt dry so that the calibrated equipment functioned properly, and instruction for all the operators so they were aware of the problems that excess salt use causes made possible a reduction in use of salt.
3. Surface application of 22-34 t/hm^2 (10-15 tons/acre) of gypsum lowered the sodium levels 30-55 percent, whereas sodium levels increased 1-24 percent for the untreated plots.

REFERENCES

1. F.E. Hutchinson and B.E. Olson. Relationship of Road Salt Applications to Sodium and Chloride Ion Levels in the Soil Bordering Major Highways. HRB, Highway Research Record 193, 1967, pp. 1-7.
2. F.E. Hutchinson. Dispersal of Sodium Ions. Maine State Highway Commission, Augusta, Technical Paper 71-10C, Sept. 1971, pp. 2.
3. K.M. Jacobs. Dispersal of Roadway Salts. Maine Department of Transportation, Augusta, Technical Paper 78-4, Feb. 1978, pp. 2-3.
4. F.E. Hutchinson. The Influence of Salts Applied to Highways on the Levels of Sodium and Chloride Ions Present in Water and Soil Samples. Univ. of Maine, Orono, Project R 1084-8, 1966, pp. 3-7.

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